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14. ABSTRACT

The Hull Bio-Mimetic Underwater Grooming (HullBUG) Vehicle System under development holds the potential to dramatically change current hull cleaning methods and their environmental impacts. Frequent use of the HullBUG, a small autonomous cleaning device, on the hulls of Navy ships in port by applying light cleaning pressure or grooming results in a cost effective solution to the underwater fouling problem.
As part of overall HullBUG development the Grooming Tool requires particular attention. This tool and variations of it have been used by Florida Institute of Technology (FIT) during several years of testing activities. FIT was assigned the task to come up with a set of parameters that FIT would want in the next generation tool. SeaRobotics was assigned the task of developing a grooming tool that would address those parameters. After review by Navy and FIT personnel the agreed to design would be built and tested. This report documents that effort.

15. SUBJECT TERMS
HullBUG, Grooming Tool, Underwater hull cleaning, autonomous vehicle

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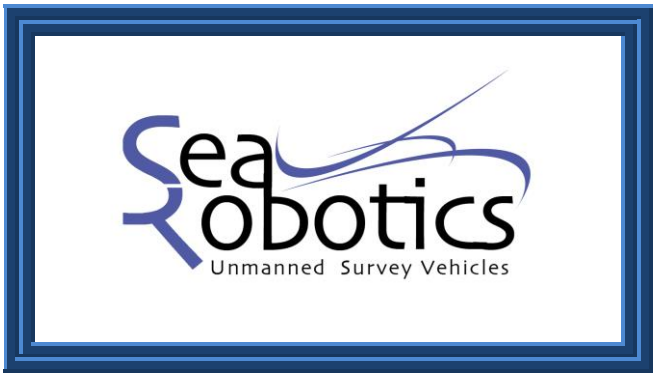

HULLBUG TECHNOLOGY DEVELOPMENT FOR UNDERWATER HULL CLEANING

QUARTERLY REPORT

EMPHASIS ON GROOMING TOOL

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8/23/13

Contents

I. Contract Information

Contract Number	N00014-09-C-0852
Title of Research	HullBUG Technology Development for Underwater Hull Cleaning
Principal Investigator	Don Darling
Organization	SeaRobotics

II. Technical Section

A. Technical Objectives

The Hull Bio-Mimetic Underwater Grooming (HullBUG) Vehicle System under development holds the potential to dramatically change current hull cleaning methods and their environmental impacts. Frequent use of the HullBUG, a small autonomous cleaning device, on the hulls of Navy ships in port by applying light cleaning pressure or grooming results in a cost effective solution to the underwater fouling problem. The frequency of grooming is selected based on the hull coating and the local fouling pressure on the docked ships or ships at anchor. Frequent grooming prohibits the development of mature fouling colonies and limits fouling to a manageable bio-film layer.

As part of overall HullBUG development the Grooming Tool requires particular attention. This tool and variations of it have been used by FIT during several years of testing activities. FIT was assigned the task to come up with a set of parameters that FIT would want in the next generation tool. SeaRobotics was assigned the task of developing a grooming tool that would address those parameters. After review by Navy and FIT personnel the agreed to design would be built and tested.

B. Technical Approach

Upon receipt of FIT provided parameters SRC would take these parameters and propose a mechanical configuration that met them along with the electrical requirements to power the new Grooming Tool. A conceptually designed SolidWorks model would be generated to better understand the packaging and mounting of the tool on the FIT vehicle. Motors and controllers would be sized for the expected loads and incorporated into the solid model. After review by Navy and FIT personnel the model would be refined and updated. Once approved, detailed drawings of the Grooming Tool would be generated. These drawings would be vended out to approved vendors for quoting. Quotes would be obtained for different levels of production in order to better understand the savings associated with buying more. Once a good pricing model was developed and quantity purchased determined, parts would be vended out and manufactured. These parts would then be assembled at SRC. A test program would then follow to fully qualify the design.

C. Progress Summary

Development efforts to date have emphasized the need to provide a stronger acting and more compliant Grooming Tool. To that end it was determined that a new Grooming Tool would be designed, technically reviewed, constructed and tested.

The following sections summarize the project's current status:

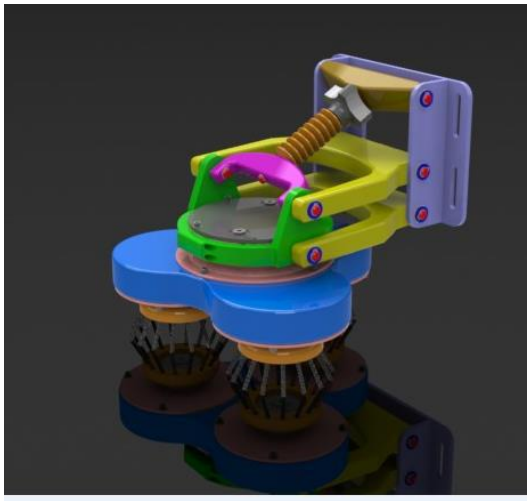
1. FIT Supplied Parameters

Based on grooming tool studies, FIT has developed a set of specifications that will be the basis of future grooming tool research. More power, more speed and optimal brush to brush center locations were the dominant themes. The following specs were provided by FIT as guidance for future Grooming Tool design.

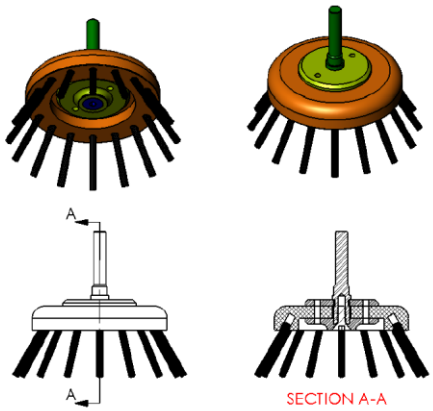
- 1000 RPM
- 240 mNm per brush
- 12 cm center to center distance

2. SRC Conceptual Design

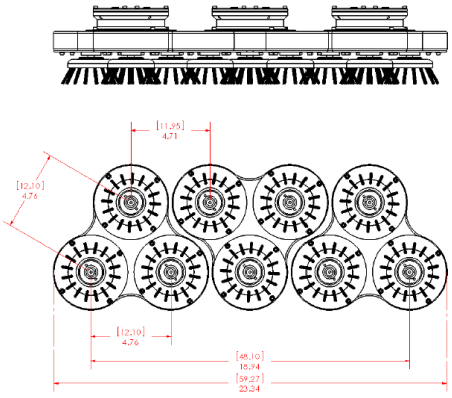
After a fairly extensive review of various motors/gearboxes and mounting combinations a 3 headed tool appeared to be the most logical concept to pursue. Three brushes are mounted to individual planet gears that are connected to a central sun gear that is directly connected to the motor. That motor gear box combination is mounted in a vertically compliant mechanism that provides approximately 3.5 inches of vertical travel. Three of these three headed tools are mounted in close proximity such that 9 brushes are operating and the 12 cm center to center distance is maintained. A conceptual layout of how these tools might be positioned on the vehicle was presented during a teleconference on 4/12/13. Grooming tool brush holder mount was discussed as a potential trouble spot.



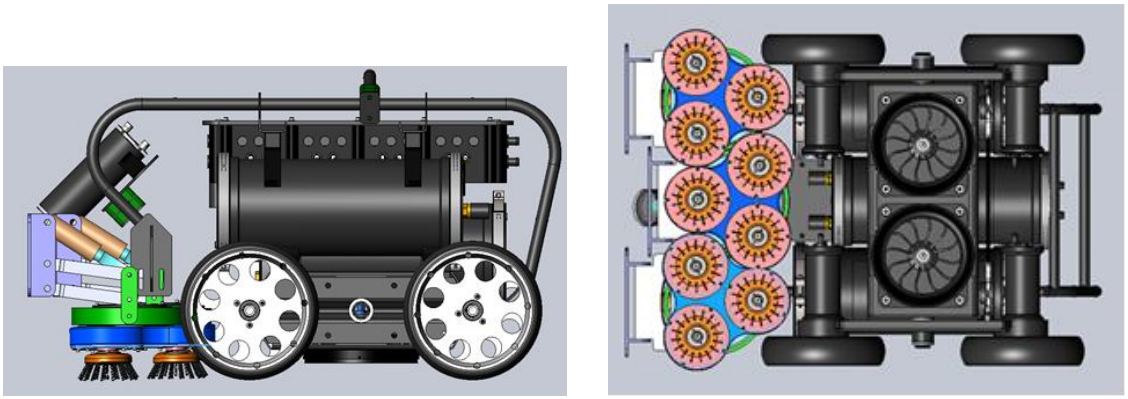
3 Headed Tool and Vertical Compliance Mechanism



Brush Holder Mounting Scheme



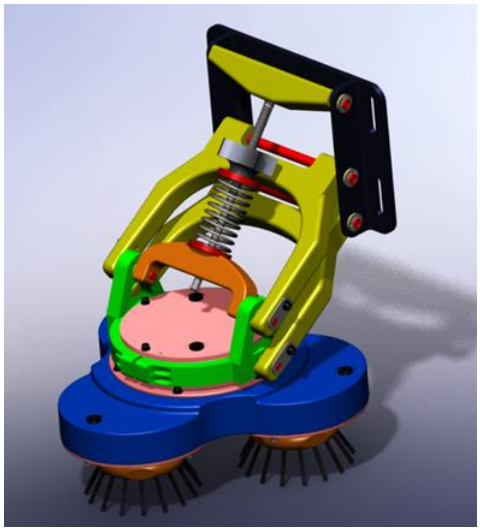
12 cm Center to Center Distance Mounting Configuration



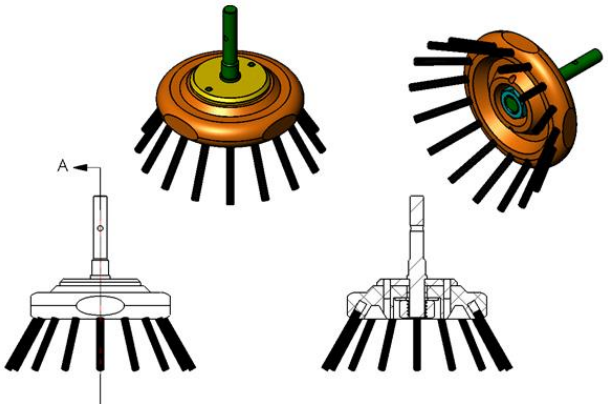
Conceptual Location of 3 Grooming Tool Assemblies

3. Navy and FIT Design Review

A telecom was held on 7/17/13 to discuss the more mature design. The Grooming Tool Brush Holder Mount had been redesigned to more closely mimic commercial products and to limit downtime from the possibility of galled stainless steel fasteners.



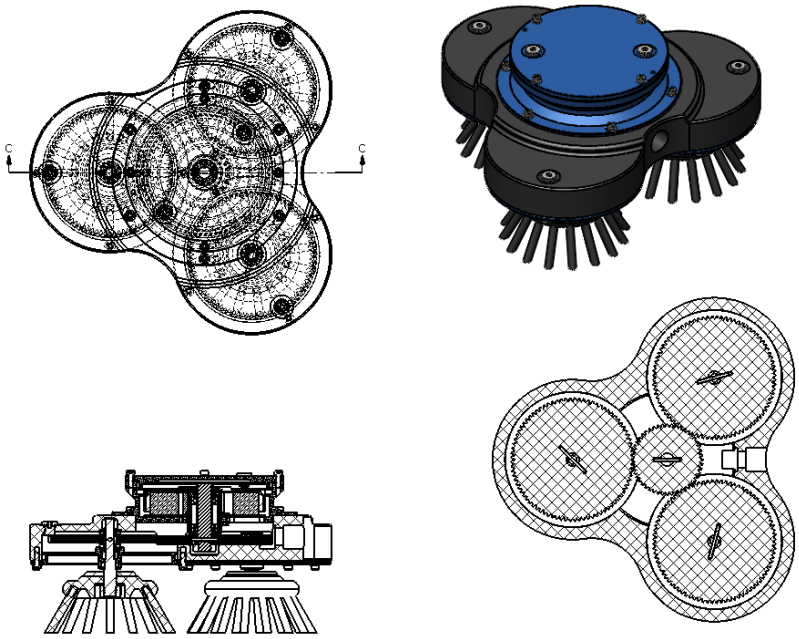
Updated 3 Head Grooming Tool Concept and Compliant Mount



Updated Brush Holder Mounting Concept

4. SRC Detailed Design

All of the parts for the 3 headed tool were detailed, dimensioned and tolerances added to enable quoting by commercial machine shops. A top assembly drawing was created that identified all machined parts as well as all purchased hardware



Top Assembly

5. SRC Production Pricing

Detailed drawings were submitted to vendors for quote in varying quantities. As expected prices per unit would drop when total purchased quantities increased. SeaRobotics, ONR and FIT discussed the idea of buying more units to take advantage of the price break with the accompanying risk of losing money if testing obsoleted some parts. The idea of building one and testing it before building others was also discussed and determined to be the least expensive way forward with the most impactful information set developed for the money spent.

During this period an effort was made to estimate the cost of a reasonably simple test device that consists of an underwater rotating disk.

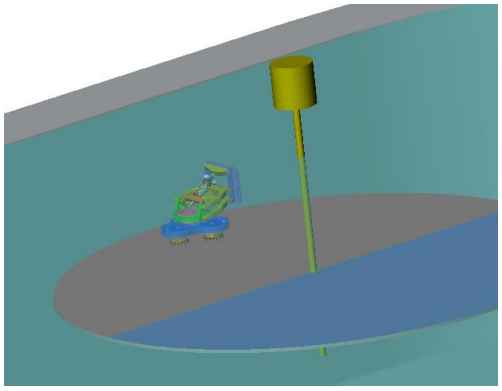
A summary of the single unit Grooming Tool, Compliance Mechanism, control system and test fixture costing is presented below.

3 Head GT Development, Production and Testing Cost Estimate			
Item		**Description**	**Total Lab and Mat thru G&A, Profit and Contingency**
Item 1		**GT Project Management**	
1		4 Weeks of Project Management	12,366
		Item 1 Total	**$ 12,366**
Item 2		**GT 3 Head Tool and Compliance Mech**	
1		Qty 1 for testing--3 Head Tool	18,471
2		Qty 0--Compliance Mechanism	-
		Item 2 Total	**$ 18,471**
Item 3		**GT Control**	
1		Qty 1--OIS initiated Outside Control of 3 GT Heads	21,645
2		0	-
		Item 3 Total	**$ 21,645**
Item 4		**Tethers**	
1		Qty 0--FIT Long Tether + Spare	-
2		Qty 1--Short Tether for SRC testing	2,366
		Item 4 Total	**$ 2,366**
Item 5		**GT Mounting and GT Assy--on Hold**	
1		Guardrail	-
2		GT Mount	-
3		GT Assy	-
		Item 5 Total	**$ -**
		Testing	
		Test Fixture--Rotating Disk	12,324
		Testing	11,031
		Test Modifications	8,339
		Engineering Support	4,328
		Item 5 Total	**$ 36,022**
		Totals	**$ 90,869**
		Total Direct Labor and Material	**$ 40,872**

Single Unit Grooming Tool, Compliance Mechanism and Testing Effort Costing

6. Production and Testing Strategy

After general review of several different production and testing strategies it was determined that a single 3 headed Grooming Tool and Compliance Mechanism be constructed for extended testing at SRC. A dedicated rotating disk type testing mechanism would be designed and constructed. Functionally the disk rotating underwater would allow the Grooming Tool to run continuously over a constantly moving surface. The rotating disk could be painted with more than one different coating allowing the grooming tool to run over different coatings in one revolution of the disk. In this way the grooming tool and compliance mechanism would be endurance tested as well as the wear resistance of the paint. Making the testing even more realistic, bumps and divots could be added simulating the varying surfaces found on a ship hull. This constantly rotating device could run virtually unattended for long periods and work to qualify the Grooming Tool, compliance mechanism, the brushes and the paint they are designed to groom.



Underwater Test GT Test Fixture

III. Near Term Priorities

A. Grooming Tool and Compliance Mechanism Fabrication

Quotes and quantity discounts on HullBUG and Compliance Mechanism have been received. The work needs to be apportioned to the appropriate vendors that can provide the best price and delivery.

B. Controller GFI Review

The FIT HullBUG electrical system is currently undergoing an upgrade that includes Ground Fault Interruption on the 120 AC side of the system and Ground Fault Detection on the DC side. Once the design and testing aspects of this upgrade are complete the proposed controller arrangement for the Grooming Tool Test Fixture should be reviewed for similar electrical issues.

C. Controller and Cabling Detail Design

The design of the GT controller and cabling needs to be finalized and schematic drawings completed. The final design needs to be reviewed by ONR and FIT.

D. Controller and Cabling Procurement and Assembly

After review by ONR and FIT the controller and associated cabling and parts can be procured and assembled.

E. GT and Compliance Test Fixture Design

The design of the GT and Compliance Test Fixture is required along with a parts list for procurement. The design needs to be reviewed by ONR and FIT.

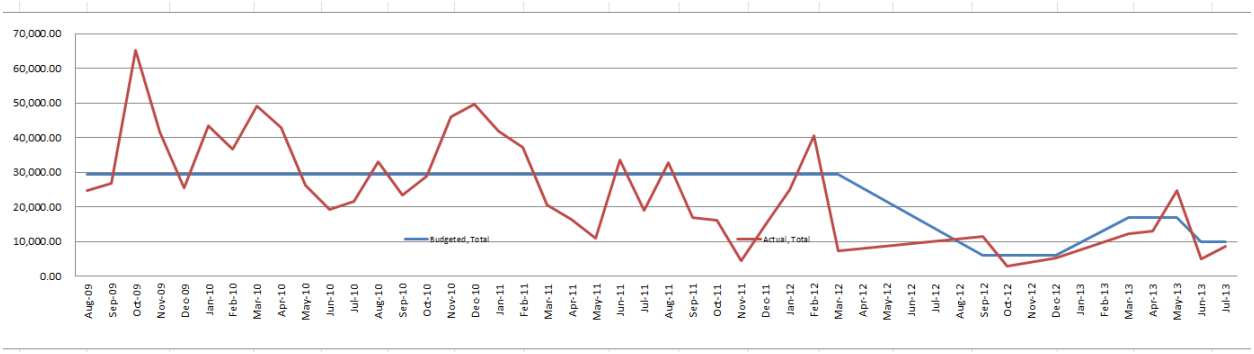
F. GT and Compliance Test Fixture Fabrication

After review by ONR and FIT the GT and Compliance Test Fixture and associated parts can be procured and assembled.

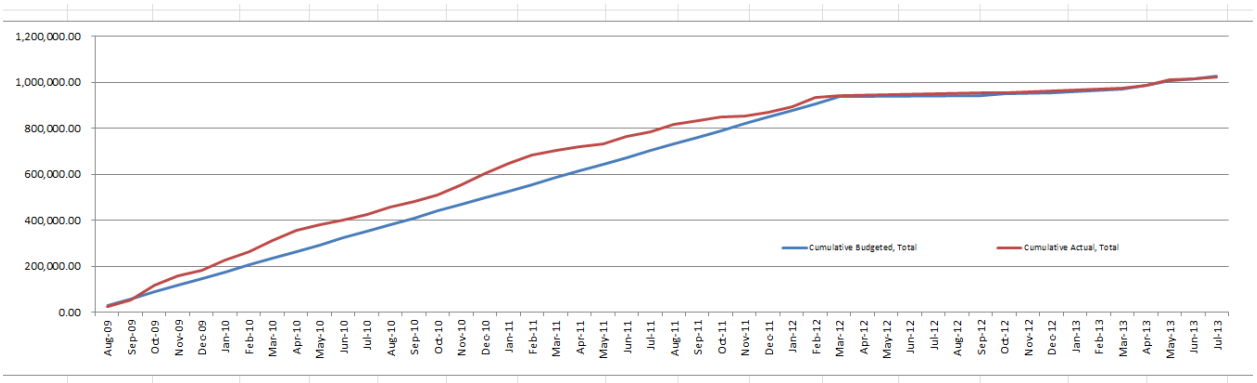
IV. Financial

The following charts and graphs detail the expenditures to date.

Major Cost Elements			Amount for Current Period Billed	Prior Billings	Cumulative Amount From Inception to Date of This Billing
Direct Labor			3,991.92	458,723.64	462,715.56
Onsite Overhead Rate	57.11%	of Direct Labor	$ 2,279.79		
Direct Material			$ -	81,170.71	81,170.71
Travel			$ -	4,507.09	4,507.09
Subcontracts			$ -	-	0.00
Total Direct Costs			$ 6,271.71	781,019.80	787,291.51
General and Administrative	28.71%	of Direct Costs	$ 1,800.61	206,141.93	207,942.54
Total Costs			$ 8,072.31	987,161.74	995,234.05
Fix Fee Earned	6.00%	of Total Costs	$ 484.34	59,229.05	59,713.39
Contract Reserves and Adjustments					
Contract Costs Withheld			$ -	-	-
Fixed Fee Withheld (10% of fee)	0.60%	of Costs Withheld	$ 48.43	5,889.01	5,937.44
Adjusted Amounts Claimed					
Current and Cumulative Costs			$ 8,072.31	987,161.74	995,234.05
Fixed Fee Billed			$ 435.90	53,340.04	53,775.95
	Total	BVN-0051	$ 8,508.22	1,015,790.10	1,024,298.32



Monthly Spend Rate



Accumulated Spending